National Defence / Defense nationale

DEFENCE AND CIVIL INSTITUTE OF ENVIRONMENTAL MEDICINE

Canada

April 1985

DCIEM No. 85-R-11

A REVIEW OF SUSTAINED PHYSICAL WORK WITH PARTICULAR REFERENCE TO THE CANADIAN COMBAT ENGINEER

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Abstract

This review was prepared as the first step in tasking sponsored by the Director of Military Engineering Plans (DMEP). The sponsor tasked the Applied Physiology Section at DCIEM to investigate the effect of sustained operations on the performance of combat engineers. In particular, DMEP wanted to establish the effect of fatigue and sleep deprivation on work output and, therefore, on the time required to complete assigned tasks (eg. the preparation of a minefield). This information will provide more accurate input to planning and may help in the formulation of doctrine and tactics.

In this review, an attempt has been made to find answers to four questions.

1. What are the energy costs of typical combat engineer tasks?

2. Can these tasks be performed without sleep for periods up to 48 hours and at what physiological cost?

3. What is the effect of sustained operations on the work output (productivity) of combat engineers?

4. Are combat engineers physically prepared to meet the physical demands of sustained operations?

With respect to the first question, it is clear that the energy cost of a task such as digging varies considerably depending on factors such as the weight lifted by the shovel, the number of throws per minute etc. This would make it very difficult to place precise values on the energy costs for specific combat engineer tasks and to use these values to estimate the hourly or daily energy expenditure. This review suggests that combat engineers will adopt a work/rest schedule in which periods of hard work are brief and are offset by periods of light work or rest. The review also suggests that the average energy expenditure will not exceed 35-40% of their maximal oxygen uptake (VO_2max). There is considerable evidence to indicate that reasonably fit young men can work at 35-40% of their VO_2max for at least eight hours without undue fatigue.

With regards to the second and third questions, there is evidence to indicate that, with 3-4 hours of sleep per day, combat engineers will be able to perform physical tasks for at least ten days. On this regimen, certain aspects of mental performance will deteriorate. It is not known whether the combination of sleep deprivation and fatigue will reduce work output (productivity) and increase the time required to complete combat engineer tasks (eg. the preparation of a minefield). There are few studies of physical work lasting longer than eight hours (the industrial working day) and none of them directly address the question of work output.

There is very little information concerning the physiological cost of sustained operations and it is difficult to extrapolate, from the data that exist, to the practical situation. However, it is clear that there are significant benefits to be obtained from improved work/rest schedules and physical fitness training.

Some information pertinent to the fourth question was provided in a recent study of sustained operations by US infantry. They indicated that there is presently too much emphasis on aerobic fitness and conditioning (running) and too little on muscle strength and power. They recommend that training programs and fitness tests for the combat arms be more closely related to the job the soldier must perform.

Introduction

There seems little doubt that future land battles in Europe will involve sustained operations. In this event, units such as the combat engineers must be prepared to endure prolonged periods of physical work compounded by sleep deprivation. To more fully understand the scope of the problem, the Director of Military Engineering Plans (DMEP) tasked DCIEM to assess the performance decrement in combat engineers working in sustained operations. In particular, DMEP wanted to establish the effect of fatigue and sleep deprivation on physical work output and, therefore, on the time required to complete assigned tasks (eg. the preparation of a minefield). This information will provide more accurate input to planning and may help in the formulation of doctrine and tactics.

The first phase of this tasking consisted of a visit to 4 Combat Engineer Regiment (4 CER) while the unit was participating in a Brigade exercise in the Military Training Area Hohenfels, West Germany. The visit provided an opportunity to observe a range of combat engineer tasks and to participate with 4 CER in a sustained operation lasting about 50 hours. The next step was to conduct a review of the scientific literature for studies related to the combat engineer problem. The purpose of this review was to identify gaps in existing knowledge and to provide a basis for proposing future research on behalf of DMEP.

The review of the literature has been completed and is presented in this report. It does not include publications from before 1950 or from foreign language sources. Of the papers reviewed, there were no investigations dealing directly with combat engineers. The information presented is therefore derived from indirectly related studies and from the general principles of work physiology. The review has attempted to find answers to the following questions:

1. What is the energy costs of typical combat engineer tasks?

2. Can these tasks be performed without sleep for periods up to 48 hours and at what physiological cost?

3. What is the effect of sustained operations on the work output (productivity) of combat engineers?

4. Are combat engineers physically prepared to meet the physical demands of sustained operations?

Combat Engineer Tasks

Although machines are used to construct an anti-tank ditch or to excavate a command post, many combat engineer tasks are accomplished by hand. Observations made during the visit with 4 CER in Germany indicate that the most physically demanding tasks performed by combat engineers

are abatis (blocking a road by felling trees), minelaying, road cratering and bridge demolition. These tasks involve the following identifiable activities:

1. Lifting and carrying (handling supplies)
2. Digging and shovelling (trenches and sandbags)
3. Hammering (pickets, camouflet tubes etc.)
4. Applying torque (augering)
5. Using hand tools (sawing, chiselling etc.)
6. Using large power tools (chainsaw, pneumatic drill etc.)

Energy Cost of Combat Engineer Tasks

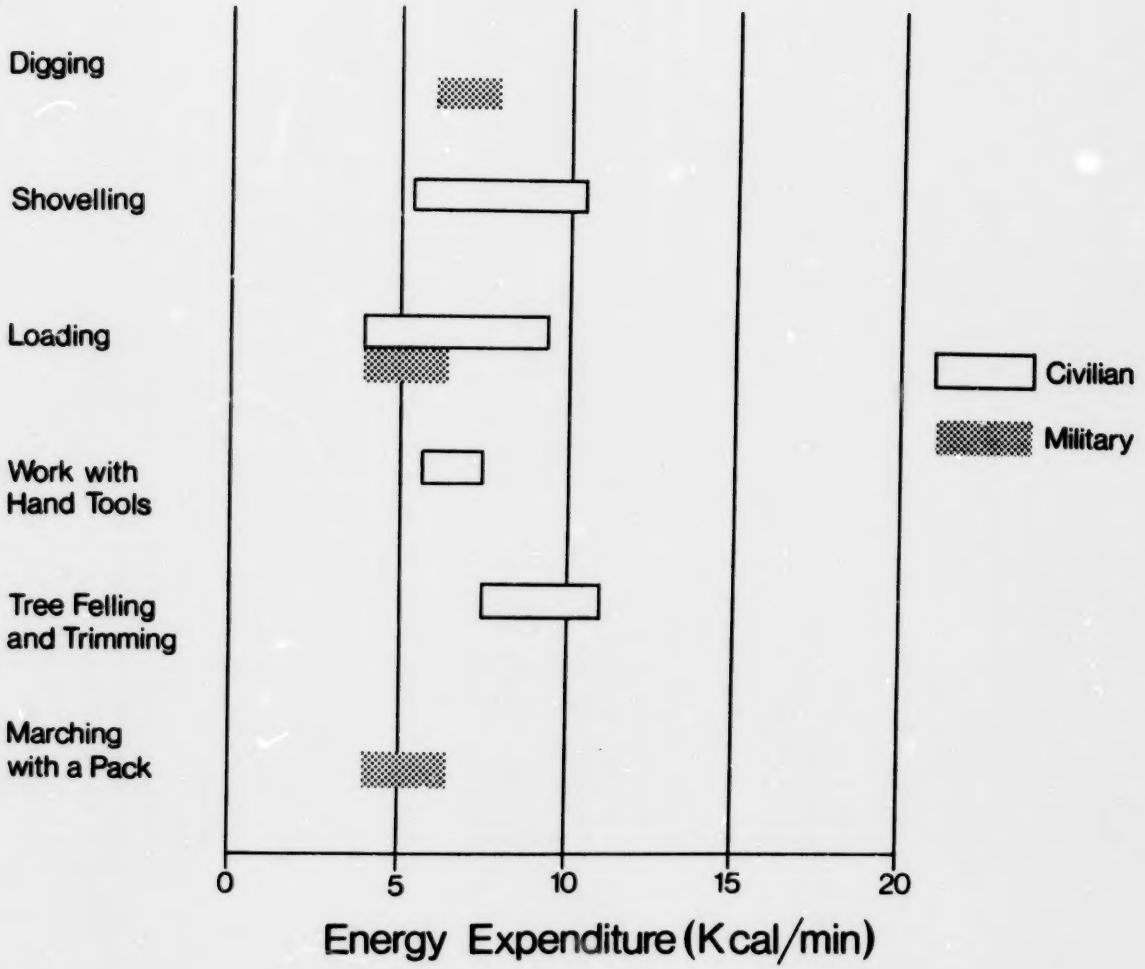
While there are no published data for the energy cost of combat engineer tasks, the energy expended for activities similar to those listed above has been measured (5,13,23,37). Figure 1 shows the energy costs, in Kcal/min, for digging, shovelling, loading etc. Although some of the data were obtained from military subjects, most refer to civilian occupations. Data for marching with a pack, a typical infantry task, has been included for comparison. The estimates of energy expenditure quoted in the literature for a single activity, such as shovelling, range from 5.3 to 10.4 Kcal/min (Figure 1). This range of values reflects the fact that energy expenditure is determined by many factors. For example, the energy expended in shovelling or digging depends on the type of soil, the weight lifted by the shovel and the number of throws per minute. Similarly the energy cost of repetitive lifting depends on the load weight, the height to which it is lifted and the lifting rate. This means that estimates of the time required to complete combat engineer tasks, based on such a wide range of energy cost, may be in error by 50%, or more.

The Energy Cost of Work Related to Physical Fitness Level

The energy costs of work, shown in Figure 1 in absolute terms (Kcal/min), have more meaning when expressed relative to the individual's maximal oxygen uptake (VO_2max). At present, VO_2max is the best available measure of cardiorespiratory fitness and the capacity for aerobic work (28,47). An energy expenditure of 5 Kcal/min is equivalent to an oxygen uptake of about 1 l/min, depending on the type of substrate metabolized by the muscles. This level of energy expenditure represents 33% of maximum for an individual with a VO_2max of 3 l/min, which is a typical value for a young relatively sedentary male weighing 75 kg (10).

Expressing the energy expenditure relative to VO_2max is one way of defining work of the same relative intensity for individuals with different fitness levels. For example, a task which requires an energy expenditure of 5 Kcal/min may represent 50% of VO_2max for one individual while for another, more physically fit individual, the same task may represent only 35% of VO_2max. All other things being equal, the lower

Figure 1. The Energy Cost of Work.



relative intensity will allow the fit man to work longer without fatigue. Thus expressing the energy cost of work relative to physical fitness (VO_2max) allows it to be discussed in terms of endurance. For example, reasonably fit young men can work at 100% of their VO_2max for only a few minutes, at 70-80% for about one hour and at 35-40% for at least eight hours (27,51). This last example, 35-40% of VO_2max, is generally accepted as the upper limit for eight hours of work in most industrial occupations (4,33,39,45).

The statement that reasonably fit young men can work at 35-40% of their VO_2max for up to eight hours without undue fatigue (27,51), refers to VO_2max determined during treadmill running. In arm exercise, VO_2max is approximately 70% of that obtained for leg exercise (7). This means that in activities where there is a significant amount of arm work, the acceptable upper limit for prolonged exercise may be less than 35-40% of treadmill VO_2max. For example, the upper limit for energy expenditure in repetitive lifting appears to be about 20-25% of treadmill VO_2max (21). An examination of the list of combat engineer activities in Paragraph 5 indicates that all of them require some use of the arms and upper body. On the other hand, observations made during the visit with 4 CER in Germany confirmed that when combat engineers work together to accomplish a single task, the heavy arm work is shared to keep arm fatigue to a minimum. Most studies of manual labour in industry have related energy expenditure to treadmill VO_2max because a VO_2max specific to each activity is impractical (4,39,45). For the purpose of this review, given the absence of a practical alternative and the recognition of the possibility of error, it is proposed to use the term VO_2max to mean treadmill VO_2max.

Energy Expenditure in a Self-paced Work Situation

Laboratory studies of physical work often use devices such as the treadmill or the bicycle ergometer on which the workload is set by the investigator. In realistic work situations, such as in industry and in combat engineer tasks, the worker sets his own pace. This pace is determined by physiological factors such as the physical fitness of the worker or his level of fatigue. It is also affected by environmental factors, such as heat and altitude, and by the restrictions imposed on movement by clothing and equipment. The self-paced work rate is also determined by factors in the job itself. For example, a chainsaw operator in the forest must allow time for the tree to fall and to move to the next one. For these and other reasons, self-paced work is intermittent with periods of hard work offset by periods of light work and rest. Estimates of the energy cost of the various tasks (Figure 1) may have little meaning in a self-paced work situation, such as probably exists for combat engineers. It may be more useful to monitor the work/rest schedule which they voluntarily adopt and to determine how work output (productivity) is affected by fatigue, sleep deprivation and other stressors in the sustained operations environment.

There have been several studies of self-pacing in which subjects walked with loads carried on the back, in some instances on a special self-pacing treadmill and in others over various types of natural terrain, for periods up to 90 minutes. Hughes and Goldman (19) and Myles and Saunders (32) found that young men voluntarily adopted an energy expenditure of 425 ± 10% Kcal/h (about 7 Kcal/min) regardless of the load carried. This self-paced work rate was equivalent to 40-50% of VO_2max for these subjects. The voluntary energy expenditure for marching is unaffected by terrain (42), by 31 hours of sleep deprivation (43), by heat stress (44) and, when expressed relative to VO_2max, does not seem to be different for men and women (14). In self-paced exercise of longer duration (3-6 hours) it has been demonstrated that energy expenditure drops to 30-40% of VO_2max, but that this level is maintained without further decline for up to six consecutive days (24,30). A study of Sherpa highlanders (33) performing as porters for mountaineering expeditions suggests that 30-40% of VO_2max is the upper limit for day-to-day work.

Self-pacing has been demonstrated in military tasks other than marching with loads. In a study of US troops in a simulated combat exercise lasting several hours (15), it was found that the upper range for energy expenditure was 400-450 Kcal/hour (6.5-7.5 Kcal/min). Those few activities involving a higher energy cost, such as the assault on the enemy position and various firefights, did not last longer than about ten miutes and were offset by periods of lighter work or rest. Psychophysical methods have been used extensively to identify safe work rates in repetitive lifting and carrying tasks (41). In one study (21), British soldiers were able to select a workload for repetitive lifting (equivalent to 20-25% of their VO_2max) that they were able to maintain throughout an eight hour working day without undue fatigue. In a subsequent study (22), voluntary work rates in repetitive lifting were shown to be unaffected by sleep deprivation.

A few studies have been made of self-paced work in civilian occupations. Investigations have been conducted by Astrand (4) for the building trade, by Spurr *et al.* (45) for sugarcane loaders, by Nag *et al.* (33) for Sherpa porters and by Rodahl *et al.* (39) for coastal fishermen. They all confirm that the average energy expenditure for an eight hour day never exceeded 35-40% of VO_2max. Although peaks in energy demand exceeded this level, they were offset by periods of rest or lighter work. The reasons why individuals self-pace at this intensity are reasonably clear. Work performed at an energy expenditure equivalent to 35-40% of VO_2max allows the body to maintain homeostasis almost indefinitely. Lactic acid does not accumulate and muscular activity can be sustained by energy derived from ingested food or fatty acids released into the blood from adipose tissue stores. In a temperate climate, heat stress or dehydration are unlikely, provided that an adequate water intake is maintained. Homeostasis is probably best exemplified by the fact that most subjects working at 35-40% of their VO_2max will have a stable heart rate of 110-120 beats/min. At levels of

energy expenditure above about 50% of VO_2max, the heart rate drifts upwards, lactic acid accumulates and the body must draw on the limited reserves of energy stored as muscle glycogen (40).

Endurance time for fatiguing work can be extended by introducing rest pauses which may be active (light work) or passive (complete rest). Furthermore, there is evidence to indicate that short, frequent rest pauses are more effective than longer rest periods provided less often (5,9). For example, Christensen et al. (9) found that when heavy work was divided into equal periods of work and rest, each of 30 seconds duration, heart rate and blood lactate were maintained at low, stable levels which were well tolerated by the subjects. When the same total amount of work was performed with work/rest periods of three minute duration, heart rate and blood lactate rose steeply indicating the onset of fatigue. One advantage of self-paced work is that it allows the worker to select a work/rest schedule in which the rest pauses are short but frequent. This practice may explain why older individuals often maintain surprisingly high levels of productivity in physically demanding jobs.

Work Periods Exceeding Eight Hours

So far, this review has considered studies where the experimental exercise period lasted only a few hours or where industrial work was limited to the 8-hour day, including breaks for meals and coffee. There is very little information available with regard to physical work performed for periods longer than eight hours. Among those studies which have looked at continuous and intermittant exercise of 24-hour duration and longer, Davies and Thompson (11) estimated the average energy expenditure of runners competing in a 24-hour road race to be 50% of their VO_2max; Houston et al. (18) measured the response of blood substrates and serum enzymes to treadmill running for six minutes at 95% of VO_2max once every hour for 24 hours; and Todor (48) measured depth perception in a single subject who walked 483 km in 107 hours. This type of experiment has little relevance to sustained combat engineer operations because the subjects were highly trained athletes (11) or were unusually motivated (48). Other reasons include the fact that the experimental protocol was too unlike that in sustained operations (18).

Studies originating from the Defence Reseach Establishments in Canada and other NATO countries tend to be more relevant to the combat engineer situation. In 1979, the British (50) measured physiological parameters in civilian subjects during seven consecutive days of strenuous hill-walking. In a joint Franco-Canadian project (30,38), physical and mental performance were measured in French infantry soldiers during six consecutive days of road marching in which they covered about 200 km with loads carried on the back. Apart from some minor foot problems, the subjects in both experiments suffered no adverse effects from the exercise. This confirms that in sustained, repetitive exercise, without the added stress of sleep deprivation, young physically trained men self-pace at 35-40% of their VO_2max, or less.

A recent study from DCIEM investigated the effect of chronic light exercise on the mental performance decrements caused by sleep deprivation (3). In this experiment, 12 subjects went without sleep for 64 hours on two occasions. On one occasion they were essentialy sedentary, on the other they walked one hour in three on a treadmill at a work rate equivalent to about 30% of their VO_2max The results showed that sleep deprivation caused a marked decrement in performance on mental tasks such as vigilance, logical reasoning, encoding/decoding and mental arithmetic. The effect of exercise superimposed on sleep deprivation was essentially neutral, with the decrement in mental performance about the same in both exercise and sedentary conditions. While it was not the main objective of the study to examine the effect of sleep loss on the ability to work and the subjects were not allowed to self-pace, it is evident from the results that the subjects' physiological responses to exercise, in particular heart rate and oxygen consumption, were unaffected by sleep deprivation. On the other hand, when asked to rate the exercise intensity on a scale of perceived exertion, the subjects seemed to find the work progressively harder as the sleep loss period went on.

There have been several other investigations into the effect of sleep deprivation on self-pacing and the perception of exercise intensity. Soule and Goldman (43) exercised military subjects on a self-paced treadmill intermittently for 31 hours without sleep. Although 31 hours did not change self-paced work rates, ratings of perceived exertion increased steadily with sleep loss. In another study, Martin (25) found that time to exhaustion for treadmill walking at 80% of VO_2max was reduced by 11% after 36 hours of sleep deprivation. Martin and Gaddis (26) also demonstrated that ratings of perceived exertion for moderate and heavy exercise were increased by 50 hours of sleep loss. A recent paper from DCIEM (29) suggests that sleep deprivation and physical fatigue may somehow interact to increase the perception of exercise intensity. It is well established (8) that, in prolonged exercise at a constant intensity, ratings of perceived exertion increase as the subject becomes tired. The concern raised by these studies is that, given the opportunity, individuals who are subjected to sleep deprivation and prolonged physical work may self-pace at progressively lower work rates, in this way maintaining a constant level of perceived exertion. As a result, the completion of tasks, such as road cratering or the preparation of a minefield, may take longer after 24 or 48 hours of sustained work without sleep. The conflicting evidence presented in this and the preceding paragraph suggests that further research is required to answer this question.

Another series of experiments dealing with prolonged work used, as subjects, cadets from the Norwegian Military Academy who were participating in training courses lasting five days (1,35,36). The studies investigated the combined effects of hard physical exercise, caloric deficit and sleep deprivation. Beginning after 24 hours, there was a significant impairment in vigilance, reaction time and encoding ability; a deterioration in mood-state; and an increase in the incidence

of symptoms related to fatigue and stress. Blood levels of stress-related hormones such as adrenaline, noradrenaline, dopamine, cortisol and growth hormone all showed increases. These and the other changes were reversed by recovery sleep. In one experiment, the hormonal response to 30 minutes of bicycle ergometer exercise at 50% of VO_2max was investigated (36). It indicated that the normal rise in catecholamines, growth hormones and cortisol occurring in response to exercise is exaggerated during sustained combat operations. Unfortunately, this series of experiments did not measure work output and the effects observed were due to a combination of stressors, one of which, caloric deficit, is unlikely to be a factor for combat engineers.

Simulation of Sustained Operations

A recent review of the effects of continuous day and night operations on the performance of the soldier (46) indicates that there are no published studies of combat engineers. However, there is relevant information concerning other branches of the combat arms. Scientists from the British Army Personnel Research Establishment (APRE) have undertaken a series of experiments, given the collective name "Early Call", in which infantry soldiers participated in military exercises for periods up to nine days with reduced amounts of sleep (16,17). During the experimental period the troops were occupied with a variety of infantry tasks such as digging trenches, defending against attack, casualty evacuation, mine-laying and mine-clearing. The results confirm that tasks with a vigilance or cognitive component deteriorate roughly in proportion to the amount of sleep lost; well learned or mainly physical tasks are not significantly degraded. They also demonstrated that well trained and disciplined troops, allowed 3-4 hours of sleep per day, could continue to perform physical tasks for at least 10 days. This is in contrast to the mental performance of these subjects which deteriorated as the sleep deficit accumulated. Unfortunately, the energy expended in the physical tasks was not measured and the results of the "Early Call" experiments do not indicate whether work output (productivity), was maintained at the initial level as the period of sleep deprivation progressed.

In 1984, a study of sustained artillery operations was conducted by APRE. The scenario called for self-propelled gun crews to set up, fire and move almost continuously for eight days. This involved sustained physical work, mainly the handling of ammunition, with varying amounts of sleep (3-4 hours per day). A preliminary report (23) indicated that the soldiers were able to maintain the necessary rate of ammunition handling and that the physical workload, per se, was not a significant problem in this scenario. Since the data analysis is incomplete (23), information with regard to other aspects of military performance is not available at this time.

Studies sponsored by the US Army on the performance of tank crews (2,12) indicate that 48 hours of sustained activity, without benefit of sleep, had no significant effect on communications, driving,

surveillance, gunnery and maintenance functions. In a personal communication (49), Dr. James Vogel of the US Army Research Institute of Environmental Medicine (USARIEM) reported a recent investigation of the physical fitness requirements for sustained combat operations (5 days with 4 hours sleep per day) by light infantry. The USARIEM study confirmed the finding of the British "Early Call" series of experiments (16,17), that four hours of dedicated sleep every 24 hours is adequate to sustain continuous light infantry offensive operations for at least five days. When pre and post measurements were compared, there appeared to be a decline in strength and muscular endurance, most noticably in the upper body. Some soldiers had difficulty in carrying loads, particularly in evacuating casualties by stretcher. The emphasis of the study was on the physical fitness requirements and there is little information in the unpublished reports presently available with regard to the effect of sleep deprivation and sustained physical work on work output.

The Physiological Cost of Sustained Combat Engineer Operations

The physiological cost of prolonged work can be defined in terms of the disturbance it causes in the balance which exists in the body's internal environment (homeostasis). This disturbance manifests itself as changes in such parameters as body temperature, heart rate, blood metabolites and stress-related hormones.

A few of the studies reviewed earlier provide some indication of the physiological cost of sustained operations. The series of experiments using cadets from the Norwegian Military Academy (1,33,36) showed that catecholamines, growth hormone and cortisol were elevated, the mood of their subjects became more negative, and the incidence of clinical symptoms increased. However, even after years of research, the significance of hormonal changes due to stress and the consequences of a changes in mental state due to stress are still poorly understood. For example, does an increase in cortisol mean an enhanced response to stress or simply a reflection of the extra strain? Does an increase in perceived exertion translate into a decrease in the for work? Since there are no definitive answers to questions like these, there is clearly a need for more research. This research should attempt to establish the practical significance of the disturbances of homeostasis documented in these and other studies of chronic stress.

In a few instances, the practical implications are obvious. For example, lower heart rates and blood lactate levels during intermittent work, where the exercise period is short and the rest pauses are frequent (5,9), reflect a reduction in the physiological cost. Obviously, one way to minimize the physiological cost of sustained operations is through the use of work/rest schedules. Another approach is to reduce the relative intensity of work by increasing the soldier's physical fitness. In these situations, research should be directed towards identifying the most appropriate work/rest cycle, the most effective fitness training program etc.

Physical Fitness Requirements of Combat Engineers

One final question to be addressed in this review is whether Canadian combat engineers have a sufficient level of physical fitness to meet the physical demands of sustained operations. Although a definitive answer to this question is not available at present, some general statements can be made regarding the physical demands of combat engineer tasks and the type of physical fitness required.

As indicated earlier in this review, VO_2max is considered to be the best measure of physical fitness as it applies to the capacity to perform prolonged hard work (28,47). Combat engineers should therefore have a relatively high VO_2max, 3.5 l/min or better. Work at 35-40% of this VO_2max will have an energy cost of about 1.4 l/min or 7 Kcal/min, in absolute terms. These values are within the range of energy expenditures shown in Figure 1. With a VO_2max of 3.5 l/min, combat engineers should be able to work for at least eight hours without undue fatigue. As regards their ability to work at combat engineer tasks for periods longer than eight hours, this review indicates that the answer to this question is unknown at present.

An examination of the list of combat engineer activities in Paragraph 4 indicates that all of them require some degree of upper body strength. An analysis of occupations in the US Army indicated that the combat engineer trade has a "high" demand for aerobic fitness and lifting strength. In a personal communication (49), Dr. Vogel of USARIEM indicated that these ratings translate into a lifting requirement of 50 kg, one time only, and a VO_2max of 3.3 l/min. In a similar survey of trades in the CF (34), combat engineers had a requirement to lift 45 kg and to make frequent lifts of 22.5 kg.

Until recently, physical fitness in the CF was assessed by means of a 2.4 km (1.5 mile) run. Running tests are a good measure of cardiorespiratory fitness (10,29) but, since they tend to favour lightly built individuals and place no demand on upper body strength, are not suitable as physical fitness tests for combat engineers. There is a clear need to identify the components of physical fitness which predict the ability to perform combat engineer tasks and to design a test which places adequate demand on these components. Some progress has been made towards accomplishing the first part of this objective by scientists at USARIEM (49). In a study of US light infantry, a battery of physical fitness tests was administered before and after a five day period of sustained operations. When the various fitness parameters were compared against military performance, strength and anaerobic capacity (the capacity for high intensity exercise that leads to exhaustion in less than 3 minutes) were found to be the most important of the fitness components tested. Times for a 4.8 km (2 mile) run and VO_2max were both unrelated to infantry performance. As a result of these findings, recommendations were made to decrease the emphasis on aerobic conditioning (running) and increase the amount of strength training. Although there was no suggestion made with regard to a specific test of physical fitness, it was recommended that fitness training be more closely related to the physical demands of the infantry soldier's job.

Conclusions

In this review, an attempt has been made to find answers to four questions.

1. What are the energy costs of typical combat engineer tasks?

2. Can these tasks be performed without sleep for periods up to 48 hours and at what physiological cost?

3. What is the effect of sustained operations on the work output (productivity) of combat engineers?

4. Are combat engineers physically prepared to meet the physical demands of sustained operations?

With respect to the first question, it is clear that the energy cost of a task such as digging varies considerably depending on factors such as the weight lifted by the shovel, the number of throws per minute etc. This would make it very difficult to place precise values on the energy costs for specific combat engineer tasks and to use these values to estimate the hourly or daily energy expenditure. This review suggests that combat engineers will adopt a work/rest schedule in which periods of hard work are brief and are offset by periods of light work or rest. The review also suggests that the average energy expenditure will not exceed 35-40% of their maximal oxygen uptake (VO_2max). There is considerable evidence to indicate that reasonably fit young men can work at 35-40% of their VO_2max for at least eight hours without undue fatigue.

With regard to the second and third questions, there is evidence to indicate that, with 3-4 hours of sleep per day, combat engineers will be able to perform physical tasks for at least ten days. On this regimen, certain aspects of mental performance will deteriorate. It is not known whether the combination of sleep deprivation and fatigue will reduce work output (productivity) and increase the time required to complete combat engineer tasks (eg. the preparation of a minefield). There are few studies of physical work lasting longer than eight hours (the industrial working day) and none of them directly address the question of work output.

There is very little information concerning the physiological cost of sustained operations and it is difficult to extrapolate, from the data that exist, to the practical situation. However, it is clear that there are significant benefits to be obtained from improved work/rest schedules and physical fitness training.

Some information pertinent to the fourth question was provided in a recent study of sustained operations by US infantry. They indicated that there is presently too much emphasis on aerobic fitness and conditioning (running) and too little on muscle strength and power. They recommend that training programs and fitness tests for the combat arms be more closely related to the job the soldier must perform.

Recommendations

The published literature appears to contain little data directly relevant to any of the questions posed in this review and almost none regarding question three (What is the effect of sustained operations on the work output (productivity) of combat engineers?). It is therefore recommended that the following experiments be carried out to obtain the missing information.

1. A field study to confirm that combat engineers voluntarily adopt an average energy expenditure that does not exceed 35-40% of their VO_2max. In this experiment, heart rate will be recorded continuously as combat engineers perform their three most physically demanding tasks (abatis, minelaying and cratering) for 8-hour periods.

2. A laboratory study at a Canadian university, under a contract administered from DCIEM, to determine whether civilian subjects can maintain paced work (simulated combat engineer tasks) at 35-40% of their VO_2max for 48 hours without sleep and to assess the physiological cost of this effort.

3. A field study to determine the effect of sustained operations on energy expenditure, voluntary work/rest schedules and work output (productivity). This study will attempt to determine whether combat engineers maintain a constant work output in spite of increasing physiological cost, or whether they self-pace at progressively lower rates as the effects of sleep deprivation and fatigue accumulate.

4. The administration of a battery of physical fitness tests to a representative sample of combat engineers to determine whether they can meet the physical demands of sustained operations.

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